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14. ABSTRACT (Maximum 200 words) <p>The principal objective of this project is to develop a calibrated simulation model which can accurately predict the effects on overall phased array system performance when conventional subsystems are replaced with optically assisted subsystems. The fabrication of high quality integrated optical components requires an accurate prediction of device performance. This is especially true in the fabrication of necessary components such as resonators where commercial software fails to predict the slot mode resonances. This is the first time a spatial mapping of the r-coefficient has been performed. Defects present a clearer picture of the inner workings of optical waveguide crystals such as LiNbO<sub>3</sub>. This is especially true of crucial quantities such as crosstalk. The effect of proton exchange may play a greater role than previously expected since we found "cracks" of defects propagating as far as 200 <math>\mu</math>m into the substrate.</p>				
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# PROGRESS REPORT

for Office of Naval Research  
for the period January 1, 1996 through June 1, 1996

## 1. **Contract Title:**

Phenomenological Modeling of Optically Assisted Phased Array Radar

### **Principal Investigator:**

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## 2. **Technical Objectives:**

The principal objective of this project remains the same and is to develop a calibrated simulation model which can accurately predict the effects on overall phased array system performance when conventional subsystems are replaced with optically assisted subsystems.

## 3. **Approach:**

The approach thus far has been to incorporate time efficient computer aided design (CAD) tools to model the entire system performance of an optically assisted phased array system. The CAD simulator will consist of three levels of phased array system analysis; a system level consisting of functional blocks, an equivalent circuit level for each of the system blocks, and a component level. Our approach has been to integrate existing phenomenological models of the separate system blocks into a computer friendly environment which can then perform an accurate overall optically assisted system performance.

## 4. **Accomplishments:**

Various components of single side band (SSB) modulator have been designed and fabricated. The designs used for this task employed a commercially available microwave design software (MDS) developed by Hewlett Packard for the microwave components, while the optical modulators are fabricated using the annealed proton exchange technique. Two important observations have come from this research: 1) MDS is not sufficient for the prediction of actual device performance, and 2) Defects present in  $\text{LiNbO}_3$  may affect device performance and these defects could also explain why device yield is not exceptionally high.

Several CPW resonators of varying feed lengths were fabricated on  $\text{LiNbO}_3$ . Additionally, the physical geometry of the resonator  $\lambda/2$  structure was also varied while keeping its impedance the same. Figure 1 demonstrates the resonator structure. The MDS predictions are shown in figures 2 and 4 while the actual

measured results are shown in fig. 3. The simulated results in fig. 4 demonstrate that mismatches in the feed impedance can create additional resonances but not the strong 10 GHz resonance. This strong resonance is probably due to the slot modes generated by the structure. We must therefore modify our analysis of these structures to include all possible excitations not just the CPW modes to be able to correctly predict device behavior.

Figure 5 shows a new experimental LST (laser scanning tomography) apparatus that allows us to observe defects in  $\text{LiNbO}_3$  samples. Measurements on samples of proton exchanged regions (used to create optical waveguides) were performed and reveal very significant defects. The proton exchange test structure is shown in fig. 6. LST measurements have shown the presence of defects along the exchanged- unexchanged region interface in a x-cut with y-propagating and z - propagating exchange stripes.  $\text{LiNbO}_3$  samples that were x-cut with z-propagating exchange stripes showed macroscopic cracks when examined under a microscope. The LST signature is also very similar to the macroscopic cracks observed. LST results are given in fig. 7. The results of the exchanged structures are also compared to the electrooptic sampling results depicted in fig. 8. The electrooptic sampling results reveal that proton exchange does provide a measurable electrooptic coefficient deviation.

### **5. Significance:**

The fabrication of high quality integrated optical components requires an accurate prediction of device performance. This is especially true in the fabrication of necessary components such as resonators where commercial software fails to predict the slot mode resonances.

This is the first time a spatial mapping of the r-coefficient has been performed. Defects present a clearer picture of the inner workings of optical waveguide crystals such as  $\text{LiNbO}_3$ . This is especially true of crucial quantities such as crosstalk. The effect of proton exchange may play a greater role than previously expected since we found "cracks" of defects propagating as far as 200  $\mu\text{m}$  into the substrate.

### **6. Future Efforts:**

- 1) Future work includes describing some anomalous resonances that we saw in the  $\text{LiNbO}_3$  single sideband structure. Since the experimental results indicate the need for better modeling tools for the design and analysis of CPW resonators, efforts are underway which will determine the impedances seen by different feed point structures. The technique will use elements of the method of moments.
- 2) A better understanding of the defect characteristics and their role in device performance is being pursued.

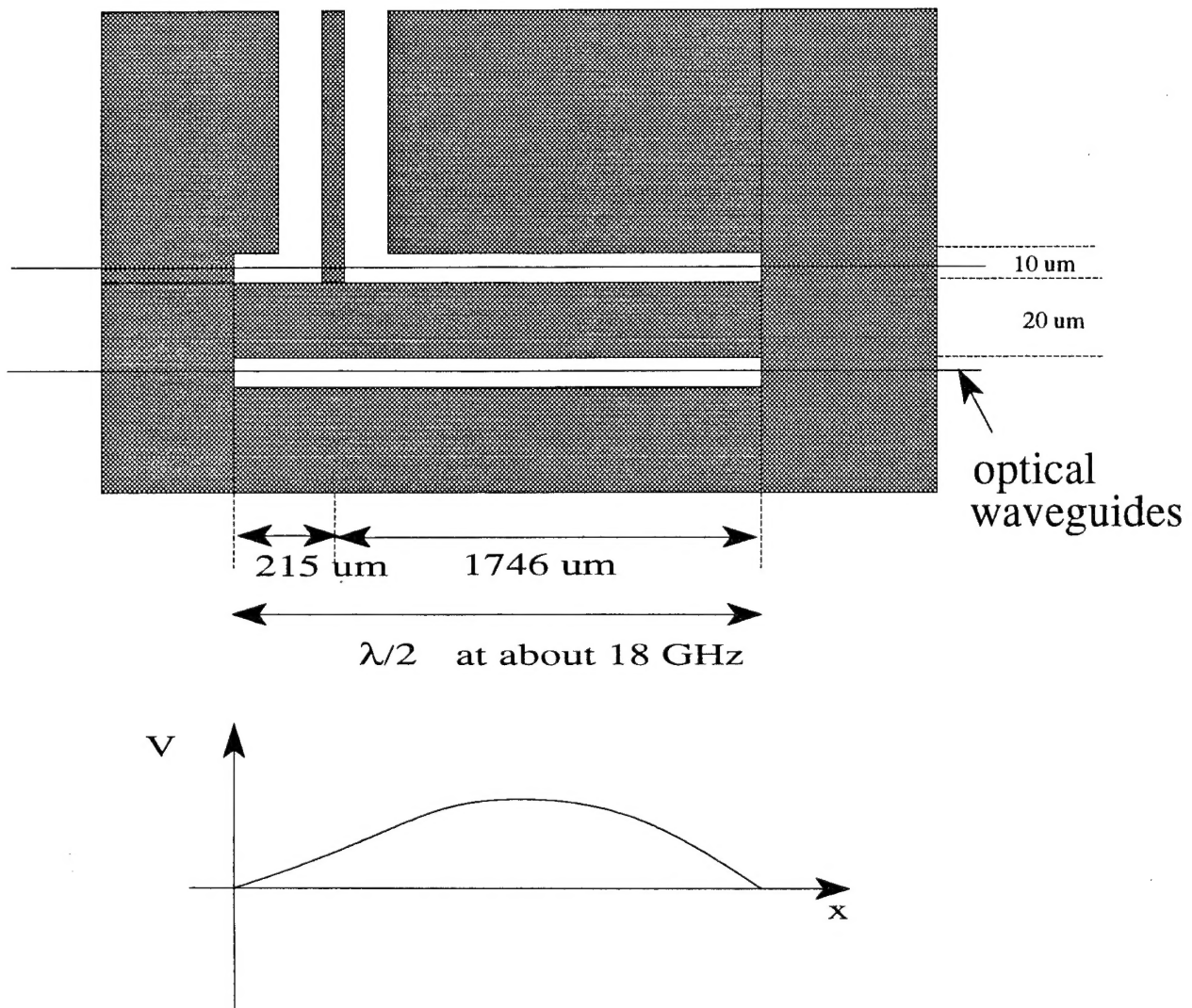
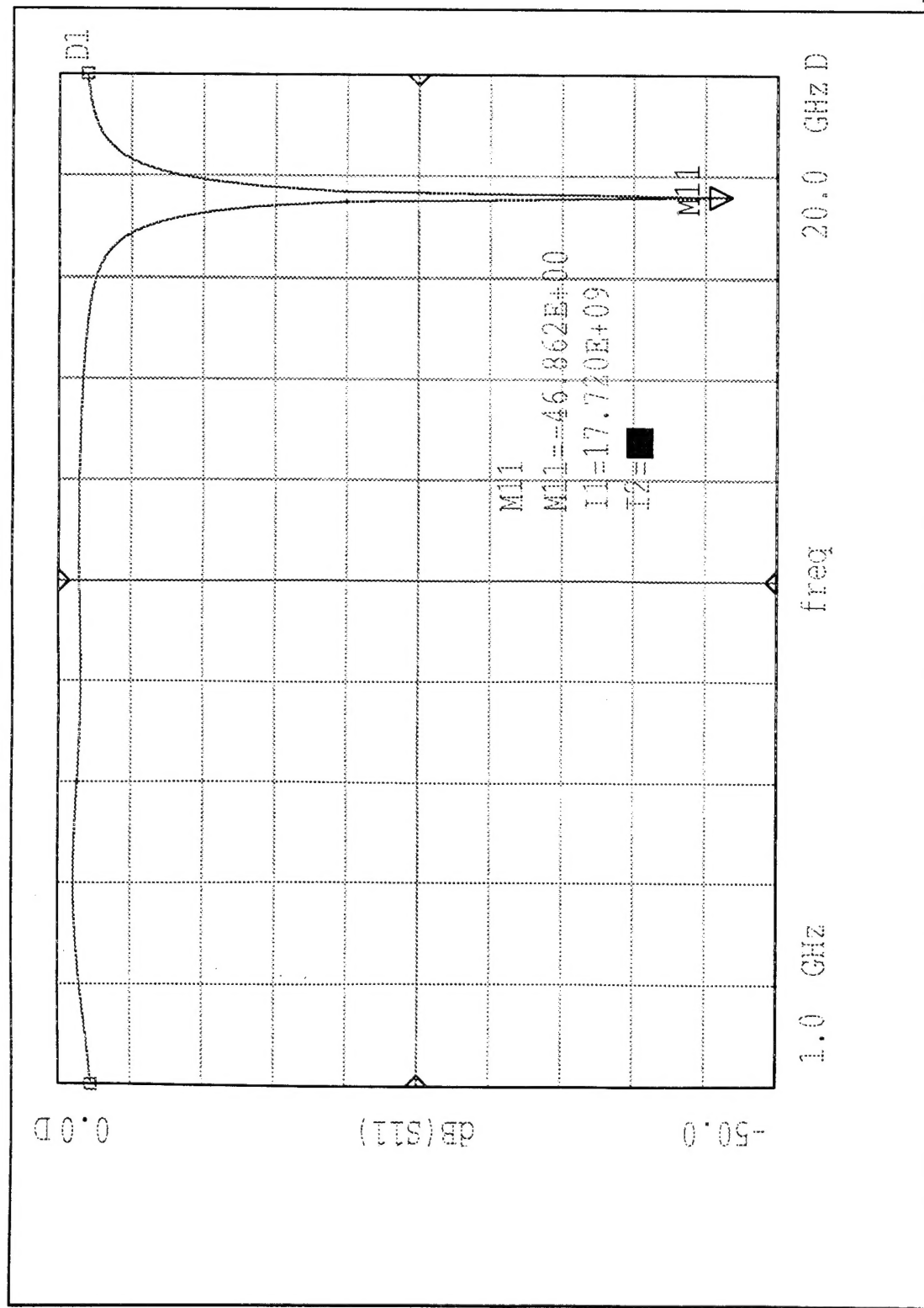


Figure 1: CPW resonator

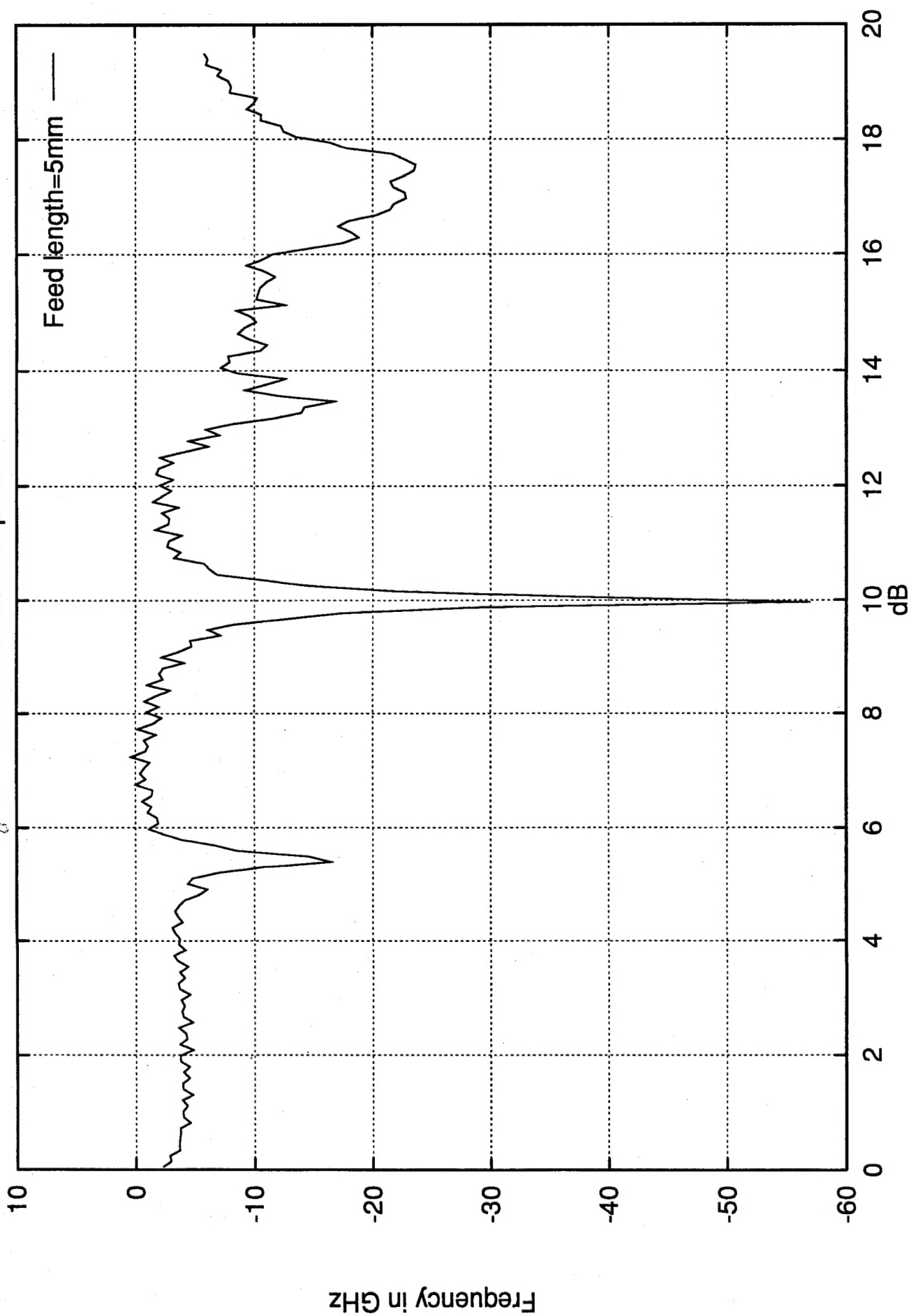
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Fig 3: CPW resonator response



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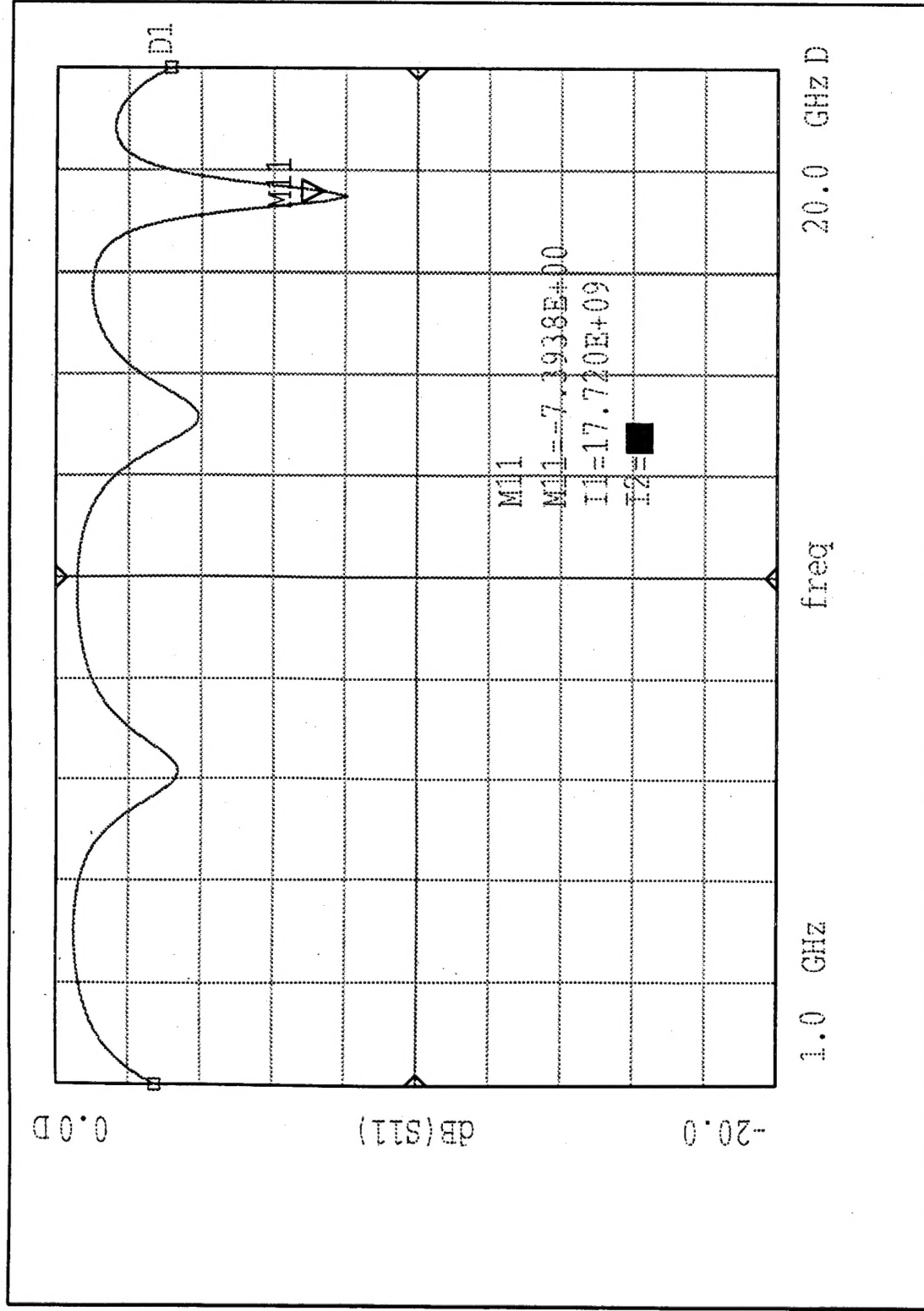
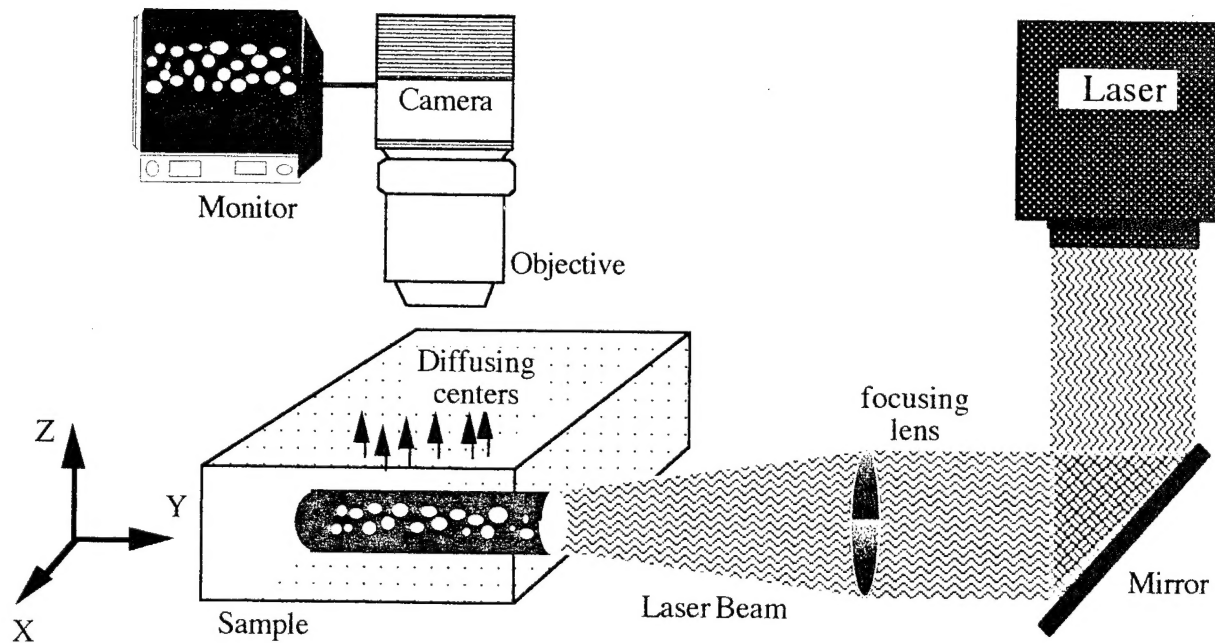


Fig 4: MMS Simulation of the antenna structure for the 17.7 GHz band



# Experimental Setup for Laser Scanning Tomography



## Characteristics :

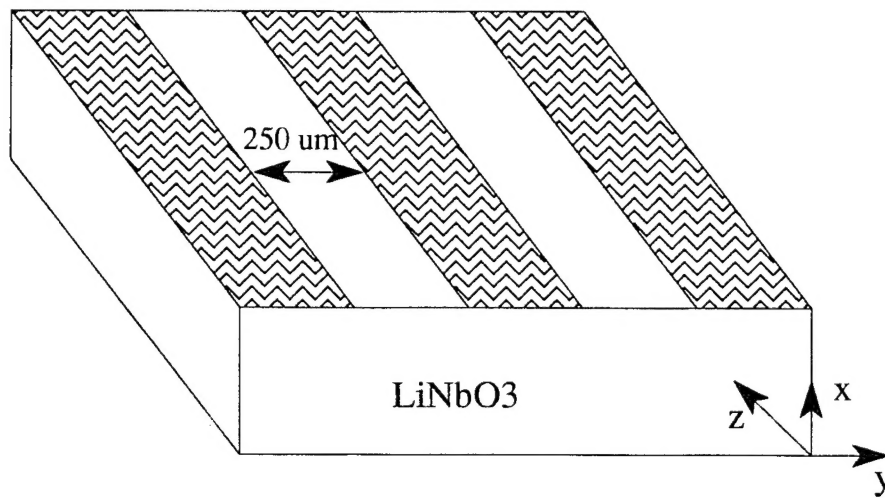
COHU CCD Camera : 754(H) X 488(V)

Maximum of resolution : 0.3 (H) X 0.4 (V)

Sensitivity : High sensitivity due to the technique of dark field  
and high sensitivity of the camera

Maximum density of defects detected is about  $9 \times 10^{12} / \text{cm}^3$

Step #1: Proton exchange sample



Step #2: Evaporate electrodes for EO sampling

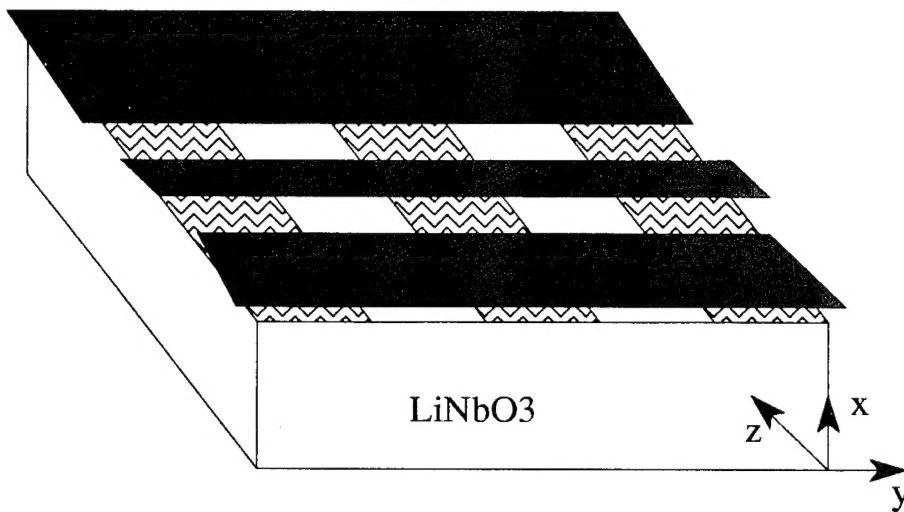


Figure 4 Experiment to map spatial variation of r-coefficient in LN samples due to proton exchange

Figure 1 LST signature of z-directed exchange stripe



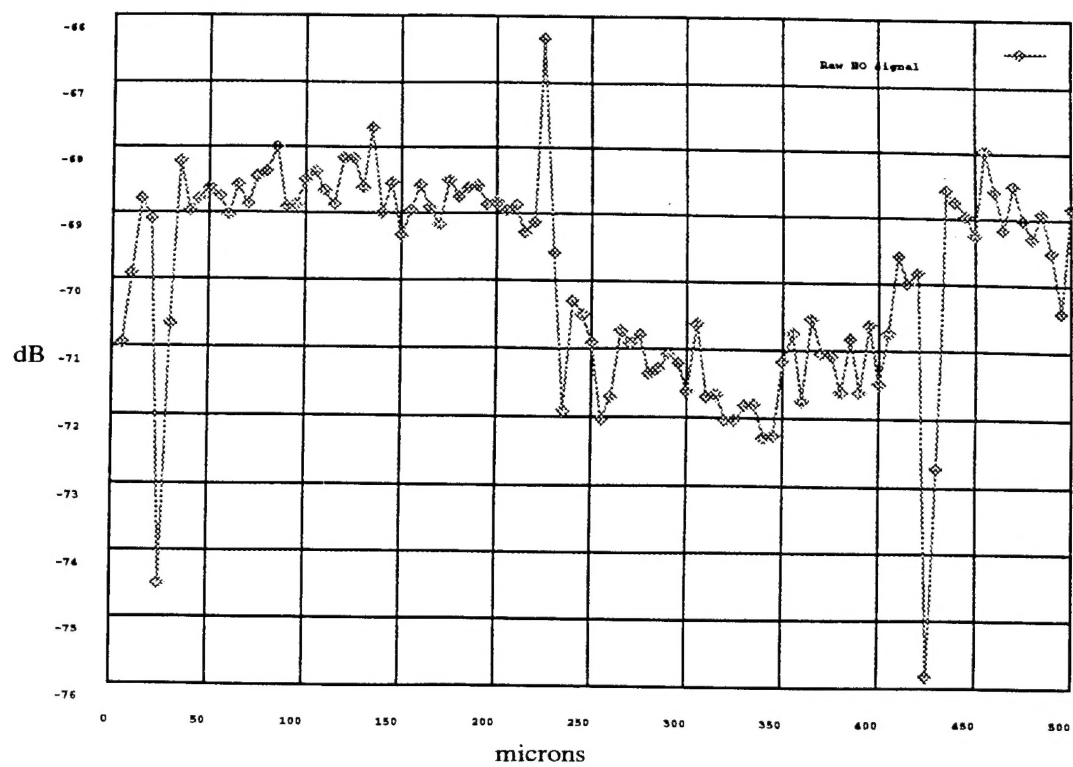


Figure 8: EO signal variation across exchanged and un-exchanged regions

Fig 8

## 7. Publications and Presentations Partially Supported Under This Grant January 1, 1996 through June 1, 1996

- (1) K. Y. Chen, P. B. Biernacki, S. Buchheit, and A. R. Mickelson, "Noninvasive Experimental Determination of Charge and Voltage Distributions on an Active Surface," *IEEE Transactions on MTT*, Vol. 44, 7, pp. 1-10, July, 1996
- (2) P. D. Biernacki and A. R. Mickelson, "Electrooptic sampling for measuring proton (H+) exchanged induced defects in LiNbO<sub>3</sub>," *Ins. Phys. Conf. Ser No. 149*, pp. 161-164, 1996
- (3) A. R. Mickelson, "Defect Studies in LiNbO<sub>3</sub>," *Ins. Phys. Conf. Ser No. 149*, pp. 7-12, 1996
- (4) D. Benhaddou and A. R. Mickelson, " Laser Scanning Tomography Studies of Lithium Niobate Crystals," *Ins. Phys. Conf. Ser No. 149*, pp. 139-142, 1996
- (5) P. D. Biernacki, Henry Lee, and A. R. Mickelson, "Evaluation of Defect Related Diffusion in Semiconductors by Electrooptic Sampling," *IEEE J. Quantum Electronics* Vol. 1, Dec. 4, 1995, pp. 1037-1046.
- (6) P. D. Biernacki and A. R. Mickelson, "Impedance Matching of Laser Diodes Using Packaged Microstrip Lines: Active and Passive," *IEEE Lasers and Electro-Optic Society* vol. 1, **OPMR3.1** pp. 238-239, Oct. 30-Nov. 3, 1995.
- (7) Raghu Narayan, and Alan Mickelson, "Design and Fabrication of Single Side Band (SSB) optical Modulator," *Digest Of The LEOS Summer Topical Meeting*, **ThB4** pg. 34, (1995).

## 8. Participants:

Professor Alan R. Mickelson  
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